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DEVELOPMENT OF FIRE RESISTANT/HEAT RESISTANT SEWING THREAD

by
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14. ABSTRACT
This report documents work carried out by Service Thread to show that domestic technology exists which would reduce base fiber costs, versus current Nomex and Kevlar type threads and the processes and costs associated with such threads. Multifilament polyester yarn was used as a core, treated and untreated. Modified acrylic fiber (Pyro-Tex) was used as the sheath. Core to sheath ratio was 50:50. The NeC 16/2 construction offered excellent physical properties. Modified acrylic fiber shed during processing and bi-component construction could not be dyed successfully to a solid, level Tan 499 shade. Finished thread sewed satisfactorily at high speeds; however, it shed severely during sewing trials, indicating fiber tenacity was too low for use in a sewing thread construction. It is expected that a polyester core treated with a flame retardant finish and wrapped with Nomex fiber, with a core to sheath ratio of 70:30 will offer a high performance, low cost sewing thread with required fire resistant/heat resistant properties.

15. SUBJECT TERMS

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COSTS	SEWING	FILAMENTS	ARMY PERSONNEL	PERFORMANCE(ENGINEERING)
CORES	SAVINGS	REDUCTION	TENSILE STRENGTH	
YARNS	THREADS	SEWING THREAD	STRENGTH(GENERAL)	

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1. Introduction

An award was made by the Natick Soldier Research, Development and Engineering Center (NSRDEC) to Service Thread based on Service Thread's proposal titled "83-Fire Resistant/Heat Resistant (FR/HR) Sewing Thread", dated 1 August 2014, which was submitted in response to the Broad Agency Announcement (BAA), for Basic and Applied Research, Solicitation Number W911QY-13-R-0032, and all work was performed in accordance with said proposal during the period of October 2014 to June 2015.

The work outlined in this proposal fits within the scope of work of the BAA, specifically, Special Focus Area: Textile Technologies. Service Thread's proposal is hereby accepted in its entirety by the government unless otherwise revised by this contract and is incorporated by reference. The technological area under investigation is FR/HR sewing threads using core spinning technology.

The purpose of this paper is to determine if a domestic capability and/or technology exists which will reduce base fiber costs in conjunction with enhanced thread manufacturing processes which lend to more modernized high speed thread production, versus current Nomex and Kevlar type threads and the processes and costs associated with such threads. Service Thread's goal is to offer a sewing thread which would reduce cost, offer excellent fire and heat resistant properties, have adequate strength and good elastic properties for sewing, be able to be easily dyed, offer excellent UV resistance, and not slice through sewn seams during normal use.

Currently there are four Government FR/HR type thread specifications consisting of either Nomex or Kevlar fibers or filaments. US Army Specifications include: A-A-50195, A-A-55195, A-A-55217, and A-A-55220, and all of these are used in the fabrication of Military items. There are several disadvantages and issues associated with the current supply chain, mainly:

- Thread materials are derived from a sole-sourced fiber supplier.
- Color matching is difficult and expensive.
- Solution Dyed shades are no longer available and as a result, thread cost has increased considerably.

- Field experience has proven that these threads offer limited stretch - threads tend to slice through sewn seams and base outer shell material, creating open seams. A recent evaluation of USMC Combat Gloves showed a high incidence of open seams on palms and finger tips due to Kevlar actually slicing through the Lockstitch 301 at the interlock points of the stitch lines. This is due to the low stretch and extreme toughness of Meta and Para Aramid materials.
- Field experience has also proven that these threads offer limited UV resistance, color fading and reduced strength.

Creating a domestic supply chain for FR based sewing threads would offer several advantages and benefits: lower the cost of FR garments, lessen the current long lead times for FR thread production and ensure faster delivery times.

When considering alternative materials to the Meta and Para Aramids referenced earlier, there are certain major requirements which must be taken into consideration, mainly that threads shall:

- Be compliant with Berry Amendment, 10 USC 2241, and Defense Federal Acquisition Regulation Supplement (DFARS) Clause 252.225-7012 Preference for Certain domestic Commodities;
- Meet FR requirements with minimum burning, no melt drip, in combination with sufficient strength and elongation to sew uniforms and gloves and offer minimum of 500 °F heat resistance in order that a typical combat uniform fabricated with such thread(s) survives a ASTM-F-1930, 4 sec manikin heat test with no significant loss in Seam Efficiency;
- Be capable of being dyed to typical military shades;
- Offer colorfastness properties;
- Offer Ultra-Violet resistance;
- Be capable of withstanding 50 home launderings;
- Offer minimum shrinkage;
- Resist discoloration;
- Be capable of withstanding high speed sewing conditions and associated needle heat, and
- Be available in multiple Tex sizes.

Since fibers are available which offer the protective properties sought by the US Army, Service Thread proposes producing a sewing thread developed from a core yarn. The strength member, referred to as the Core, will be made from high tenacity polyester with or without a FR/HR treatment, and the protective member, referred to as the Sheath, will be developed from Modified Acrylic fibers. The Core will offer sufficient strength and elongation to sew uniforms and gloves. The percentage Sheath shall be sufficient to offer minimum of 500 °F heat resistance in order that a typical combat uniform fabricated with such thread(s) survives ASTM-F-1930, 4 sec manikin heat test with no significant loss in Seam Efficiency.

The initial proposed design, known as Phase 1, incorporates a HT Polyester core with no FR/HR properties as it is anticipated that the sheath will offer all the required protection. However, should said protection to the core be inadequate, a FR/HR treated core would be used and would be known as Phase 2, which would require an additional process. If a treated core is found to be necessary, then it may be possible through additional work to modify the core to sheath ratio to allow for a higher core denier and reduction in percentage sheath, which would yield a stronger thread. Proposed materials will be as follows:

Sheath – PyroTex® Modified Acrylic – 2.5 Denier, 50 mm in length. Limited Oxygen Index (LOI) 43%.

Core – High Tenacity Multifilament Polyester, resistant to most chemicals and solvents.

Design Core to Sheath Ratio will be 50:50.

PyroTex® fiber is offered by Pyro-Tex and boasts the following properties [1]:

- Flame and Heat Resistant – LOI is 43%
- Acid and Alkaline Resistant
- UV Resistant
- Solvent Resistant
- Will Not Melt
- Will Not Drip
- Will Not Smoke
- Will Not Produce Toxic Fumes

- Dyeable
- Distributor for Pyro-Tex has stated that this fiber is available in solution dyed form, with several colors available, e.g. Tan 499.

The high tenacity - multifilament polyester core will be used without a FR/HR finish in Phase 1 and with a FR/HR finish in Phase 2.

Standard HT polyester is readily available in various deniers and is a low cost item when compared to Kevlar or Nomex. The polyester core will offer the strength required to perform the high speed sewing and elongation required to form a consistent loop and subsequent seam.

It is anticipated that when the modified acrylic sheath component represents 40 – 60% of the core spun yarn construction, the polyester core will have sufficient protection from the sheath and will not be required to have FR/HR properties. Modified acrylic fiber is a stable fiber which chars and expands when exposed to an open flame, thus blocking the flow of oxygen [2]. However, should a FR/HR core be more desirable, a suitable treatment can be applied prior to the spinning process.

The proposed core thread constructions can be made available in multiple Tex sizes ranging from Tex 30 to Tex 730 and could be modified to widen this range; however, the total number of constructions should be less than the 49 listed in US Army Specifications A-A-50195, A-A-55195, A-A-55217, and A-A-55220. It is anticipated that the total number of core thread constructions required to service all sewing requirements will be around 11.

Core spinning is an established technology used commonly in the production of apparel sewing thread. The process can be specific to short or long staple fibers of varying denier.

The process of making a core spun sewing thread commences with fibers being delivered to an opening room in bale form, and because fibers from the same origin are never identical in physical properties e.g. denier, tenacity, length, crimp and finish, it is good practice to blend fibers by picking from several bales laying side by side. The opening room, through a series of beaters and blowers, open and transport fiber clumps to the cards where a fiber mat is formed and presented to the cards. These cards open and straighten the fiber bundles, drawing them down to form a web which is formed into a sliver.

This card sliver is then blended and drawn down further by running eight ends through a drawframe (first passage). To improve the quality even further, particularly evenness, this process is repeated (known as second passage or finisher sliver). The drawframe sliver is then processed through a “speed” frame/roving frame to roving. This process draws the drawframe sliver down even further to a required hank weight. The roving hank weight will depend on the total draft to be used to during the spinning process.

The spinning process, through the choice of total draft, will reduce the fiber bundle down to the fiber count required to give the 40 – 60% cover on the polyester core which is delivered to the middle of the fiber bundle behind the front top roll. The core multifilament polyester yarn will depend on the yarn size being spun. It is anticipated that, in order to offer the full range of sewing threads, core denier will range 70 – 660. Twist is inserted to the required level and direction, which in this case would be in the ‘S’ direction. The core spun yarn may need to be conditioned to reduce the amount of torque present and reduce the risk of kinks forming during subsequent processing. Yarn should then be wound onto a cone while being cleared of any major faults which may have formed or been introduced to the fiber bundle during processing. Core yarn can then be doubled to as many ends as the final thread requires e.g. 2, 3, 4 etc. Doubled packages can then be twisted to form the thread while imparting the required level of twist in the ‘Z’ direction. It is normally preferred to twist onto a dye tube before being placed in greige thread inventory. All twisted production should be heat set to eliminate torque. This can be achieved using an autoclave for white and a dye vessel for colored thread (whites may also be wet processed in a dye vessel). Basic dyes can be used to package dye modacrylics, modified acrylics and basic-dyeable polyesters [3].

Basic dyes are cationic dyes characterized by their substantivity for standard acrylic, modacrylic, basic-dyeable polyester fibers. The major outlets for basic dyes are acrylic and modacrylic fibers, on which basic dyes can impart bright colors with considerable brilliance and fluorescence. The ionic attraction between the basic dye and the sulphonic acid dye sites in acrylic fibers is strong, which yields high color fastness to washing. The close-packed physicochemical nature of acrylic fibers and the strong dye-fiber bonding can result in poor migration and leveling properties during dye application, but impart very high color fastness to light. Cationic retarders are widely used on acrylic and modacrylic fibers to promote level dyeing and the basic dyes used should preferably be selected with the same compatibility value.

The compatibility value may range from 5 (slow diffusing) down to 1 (rapid diffusing). A compatibility value of 3 has been recommended for package dyeing [3].

Ideally, and to assist in offering the best possible quality, sewing thread should be lubricated straight from the dyed package without the use of an intermediate pre-lubrication process. This technology exists in the US and is available at Service Thread. The choice of lubricant, as well as the amount and consistency of application, is important if high sewing speeds are to be attempted.

A silicone wax formulation should be used which combines the lubrication qualities of silicone oils and waxes and will be non-flame propagating. The silicone keeps the needle cool during sewing, eliminating thread breakage and skipping. The wax component reduces needle chatter and static, stick-slip, eases needle penetration through the fabric and helps minimize skipped stitches (damage to needles is a major contributor to skipped stitches). The amount of lubricant applied should be sufficient to offer needle protection but not so much as to stain the fabric being sewn and mist while sewing.

Typical benefits of a premier sewing lubricant:

- Eliminates thread breakage
- Even distribution – no migration or staining
- Resistant to high needle heat (a needle can reach a temperature of 350 °C in a matter of seconds)
- Eliminates stick slip
- Reduces needle chatter and static
- Allows consistent loop formation and therefore less downtime
- Allows maximum sewing speeds

State of the art lube application systems should be used to apply lubricants at minimum levels required to facilitate sewing. Service Thread utilizes such a system which offers minimal variation from a selected application level. The thread is finally wound to a cone or king spool and will typically be sold as a 6,000 yd or 12,000 yd unit, or sold by the pound.

The following table shows a listing of anticipated construction which should cover all applications, with the ability to expand if needed:

TABLE 1

ANTICIPATED CONSTRUCTIONS & PHYSICAL PROPERTIES

Nominal Tex	Final Plies	Denier	NeC / Ply	Approx. Yards / Pound Nom.	Min.	Max.	Strength Min. (Lbs)	Elongation Max. %
24	2	221	48/2	20160	19152	21168	1.9	35
30	2	266	40/2	16800	15960	17640	2.4	35
40	2	360	30/2	12390	11770	13009	3.2	35
60	3	540	30/3	8268	7854	8681	4.8	35
75	2	677	16/2	6594	6264	6924	6.0	35
98	2	886	12/2	5040	4788	5292	7.8	35

Since Service Thread does not have staple opening and spinning capabilities, nor a dye house, Charles Craft was subcontracted to manufacture the core thread as specified by Service Thread, NeC 16/2 (Tex 75), and Hickory Yarns was subcontracted to dye the thread.

2. Methods and Approach

2.1 Phase 1: English cotton count (NeC) 16/2 Incorporating Untreated Polyester Multifilament Core

2.1.1 NeC 16/2 Yarn and Thread Preparation.

Location – Charles Craft, Hamer, SC.

The fiber was opened and fed by two Fiber Control Apron Feeders to three Trùtzschler TC7 Cards operating at 80 lb/h. Card sliver was delivered to the card cans at 60 grains. Eight ends of card sliver were blended and drawn down to 57 grain on a Rieter SB 851 drawframe – Breaker Sliver. To further improve quality and reduce sliver weight, eight cans of breaker sliver were blended and drawn down to 55 grains on a Rieter RSB 851 drawframe – Finisher Sliver.

1.0 hank roving with 1.28 twists per inch (tpi) was produced on a Rovematic utilizing SKF's PK-1500 drafting system.

Core yarn was produced on a Zinser RM 350 spinning frame equipped with 42 mm diameter rings and linked to a Schlafhorst Autoconer 338 equipped with Loepfe TK 840 Clearers and with air splicing for yarn joinings. The spinning frame was also equipped with manufactured creel adaptors and guides for filament pirns and for roving alignment. 170 denier polyester filament was pre-tensioned by being passed around a metal bar before going around filament guides positioned above the front cot. Roving guides and filament guides were attached to the same traverse mechanism to ensure correct alignment of both. Draft gearing was selected to deliver a fiber bundle representing NeC 32.4/1 which, with a 170 denier multifilament polyester core, gave a resultant yarn count of NeC 15.91/1 (target was NeC 16/1). Apron drafting clips were black. Twist was measured at 16.95 'S' (target was 17.0 'S'). The traveler chosen was a 7/8 HR WD #10, Flange 1. Spinning tension was good with this traveler at a spindle speed of 7,500 rpm. The target ratio of sheath to core was 50:50.

The yarn wound without generating kinks at start-up and while running, indicating that conditioning of spinning bobbins would not be necessary, and that the yarn would therefore not have to be spun using phenolic coated bobbins which are designed to resist multiple conditioning cycles. The yarn was wound at 950 yd per minute. Upon closer inspection of finished packages, yarn liveliness was such that kinks

were likely to occur at doubling; therefore, wound packages were conditioned using an H&W conditioner. After initial trials, the following conditions were chosen for minimizing torque: 20 min pre-heat; 1 h 40 min at 220 ^{o}F wet heat, and 15 min at 195 ^{o}F dry heat.

Doubling was carried out on an SSM doubler running at 550 ypm. 20 packages were doubled to a net weight of 2.5 lb.

Twisting was carried out on a Volkmann VTS-07 2 for one twister at a speed of 4,900 rpm. The target twisted level was 14.8 TPI ‘Z’. Thread was taken up on a 170 mm x 54 mm hermaphrodite rigid dye tube to a net weight of 2.5 lb.

No hand tied or mechanical knots were allowed, only air splices.

2.1.2 NeC 16/2 Dyeing To Tan 499.

Location – Hickory Yarns, Hickory, NC.

The thread was shipped to Hickory Yarns, who were subcontracted to develop procedures and recipes to dye this NeC 16/2 bi-component thread to Tan 499.

The initial approach was to use a two dye bath cycle, one with disperse dyes for the polyester core and the second bath with basic dyes for the modified acrylic sheath. Whether the disperse dye would dye or even stain the modified acrylic was an unknown for Hickory and could only be answered through subsequent trials. Adjustments to shade would be made where necessary.

2.1.3 NeC 16/2 Lubrication and Final Winding.

Location – Service Thread, Laurinburg, NC.

Dyed thread was wound and lubricated on an SSM Perciflex cone winder. 18 cones were wound with each containing 1,500 yd of thread.

2.1.4 <u>NeC 16/2 Physical Testing.</u>

Location – Service Thread, Laurinburg, NC.

The thread was tested for linear density, strength and elongation at break, single end and ply twist level and direction, dry heat shrinkage at 177 ^{o}F/2 min/9 g and lube content. The thread was also sew tested with a 301 stitch on a Juki LK-1942GA multidirectional sewing machine at 1,400, 1,800 and 2,200 spm (stitches per minute), using #8 Cotton Duck (18 oz fabric) see Appendices C and E.

2.2 Phase 2: NeC 16/2 Incorporating Treated Polyester Multifilament Core

2.2.1 <u>FR Treating of 170 Denier Polyester Multifilament.</u>

Location – Service Thread, Laurinburg, NC.

Apexical's FLAMEPROOF™ #1528, a non-toxic, durable non-halogen flame retardant for polyester was blended with water in the ratio 85:15, water:FLAMEPROOF #1528. This mixture was padded onto the 170 denier polyester core yarn at 40 yd per min and cured at 380 ^{o}F. Treated yarn was taken up using Sahm winding heads and onto a paper tube.

2.2.2 <u>NeC 16/2 Yarn and Thread Preparation.</u>

Location – Charles Craft, Hamer, SC.

Spinning creel core yarn adaptors were modified to accommodate the Sahm type take-up tubes, as well as the standard pirns used in Phase 1, eliminating the need to pirn wind treated filament.

Yarn and thread would be produced using same set-ups and procedures as Phase 1.

2.2.3 <u>NeC 16/2 Dyeing To Tan 499.</u>

Location – Hickory Yarns, Hickory, NC.

Thread was shipped to Hickory Yarn to be dyed Tan 499.

2.2.4 NeC 16/2 Lubrication and Final Winding.

Location – Service Thread, Laurinburg, NC.

Dyed thread was wound and lubricated on an SSM Perciflex cone winder. 18 cones were wound with each containing 1,500 yd of thread.

2.2.5 NeC 16/2 Physical Testing.

Location – Service Thread, Laurinburg, NC.

The thread was tested for linear density, strength and elongation at break, single end and ply twist level and direction, dry heat shrinkage at 177 ^{o}F/2 min/9 g and lube content. Thread was also sew tested on a Juki LK-1942GA multidirectional sewing machine at 1,400, 1,800 and 2,200 spm (stitches per min), using #8 Cotton Duck (18 oz fabric)

3. Results and Discussion

3.1 Phase 1

3.1.1 Yarn and Thread Production

Trùtzschler TC7 cards were already set up as standard to run 50 mm x 2.0 denier fibers such as Nomex, Kevlar, PBI or blends of the latter two. Pyro-Tex fiber was noticeably bulkier than Nomex and Kevlar fibers which led to some minor processing problems as the fiber fed differently through the ducts to the card feed system - Magnehelic differential pressure setting caused delays in the feed and therefore thin spots in the matt, which caused sliver breaks. As the thinning web was being fed by a belt feed system, it would occasionally stick to the belt and cause slubs, periodically breaking out. These problems could easily be remedied if cards were specifically being set up to run this fiber over a considerable period; however, no changes could be made during this very short run – 470 lb is a very small volume for three high speed cards. The low tenacity of Pyro-Tex® fiber (2.81 g/den versus ≥ 5.3 g/den for Nomex and Kevlar fiber) may also require a different card wire.

The material processed fairly well during the breaker drawing process with most breakouts occurring due to the slubs being generated by one particular card. The material processed well, resulting in an evenness CV% of 4.02, which is good for finisher sliver.

Twist gears normally used for NeC 1.0 hank Nomex roving, which yield 0.89 TPI, did not offer sufficient fiber to fiber cohesion with Pyro-Tex and roving pulled apart easily when a small amount of pull tension was applied. 1.0 TPI and 1.1 TPI were tried; however, both were too low. Gears were purchased for 1.28 TPI which was found to produce the desired results. Roving was then produced without any issues.

The NeC 16/1 yarn appearance was good; however, it was marginally hairier than desired, which was probably due to the high level of fiber crimp.

Linting occurred around most static contact points, particularly during winding and doubling. The appearance of the twisted NeC 16/2 construction was hairier than desired. These characteristics could be attributed to a low fiber tenacity leading to fiber breakage.

3.1.2 Dyeing

Hickory Yarns could not dye this bi-component thread a solid shade of Tan 499.

All 12 lab trials, which comprised formulations and modifications of component or dual bath processes of disperse, basic and one reluctant trial of pre-metalized acid dye formulation, failed. The thread was finally processed as a lot purely to allow for a wet process at a temperature of about 266 °F to evaluate physical properties. With the correct knowledge and/or experience, it should be possible to dye this combination of raw materials.

3.1.3 Final Winding

Phase 1 was actually wound on two occasions. The first occasion was in February and the second in May, 2015. The February dye lot was visibly streaky and off shade; it was quite evident that the two substrates interfered with each other's dye uptake; however, cones were produced so that a sewing analysis could be carried out. The May dye lot was less streaky but was still off shade.

In each case, the thread was lubricated straight from the dyed package without the use of an intermediate pre-lubrication process. The final put-up was a 7" plastic cone. Eighteen cones were produced from each dye lot (Feb and May) and each cone contained 1,500 yd. Physical properties are listed in Table 2.

TABLE 2

Phase 1 Physical Properties

	Count (NeC)	Breaking Strength (lb)	Elongation @ Break (%)	Twist Singles 'S'	Twist Plied 'Z'	DHS (%)	Lube Content (%)
Anticipated Values	8.00	6.00	Max 35%	17.00	14.80	1.50	8.00
Phase 1 (Feb)	7.10	6.25	24.52	18.50	14.57	1.28	9.03
Phase 1 (May)	7.48	5.78	21.21	18.63	14.61	1.55	6.54

Note: The Dry Heat Shrinkage (DHS) test was done in accordance with ASTM D 4974 – Standard Test Method for Hot Air Shrinkage of Yarn and Cord Using a Thermal Shrinkage Oven [4] using the following parameters: 177 ^{o}C / 2 min / 9 g. The other testing is conducted in accordance with ASTM D 204 – Standard Test Methods for Sewing Threads [5].

Anticipated physical properties were for dry, un-lubed thread, hence the lighter count.

The physical properties are acceptable and should allow for good sewing performance; however, the shade variation (green/blue streaks) along the length of the thread is a concern. The thread was analyzed using a Dino-Lite Microscope which showed that the modified acrylic was taking the dye and did appear Tan 499. It was the filament core that was showing up green through areas lacking in fiber (Appendix A and B). Microscopic analysis indicated that the polyester filament core was not totally encapsulated by modified acrylic fiber. Some disturbance of the fibers at 50:50 was expected, although not apparent random areas exhibiting minimal coverage. Fiber dye uptake was evaluated further by stripping fiber from the surface, and this showed that the fiber had indeed been dyed Tan 499. Based on this analysis, Hickory Yarns reported back with the following statement and plan for future trials:

"That green shade is definitely coming from the polyester core because the core remains white (instead of green) on the "basic dye only" samples. It is surprising that it would dye so green with the disperse dye formula, because that same formula dyes our 100% polyester the correct shade of Tan. I'm fairly certain that the mod-acrylic fiber is taking up a large percentage of the disperse red dyestuff, leaving the polyester core with just the yellow and blue dyes, which further complicates the levelness and streak problem because the more red disperse dye that exhausts onto the mod-acrylic fiber, the more green the polyester core becomes, creating even more contrast. I am going to go back to the basic dye only

samples, and try adjusting to match the standard. Then, we'll determine what to do with the core polyester."

The above dyeing trials have allowed us to cast light on a potential problem and ask the following question – under current conditions, will the modified acrylic fiber offer complete FR and HR protection? Based on the amount of green showing through the surface it is doubtful that it will and a FR treatment is probably the route that must be taken.

3.1.4 Sewing Trials

Phase 1 (Feb) thread was successfully sewn utilizing an internally developed multidirectional pattern at 1500, 1800 and 2000 stitches per minute (Appendix C) using a Juki LK-1942GA sewing machine, equipped with a Schmetz 110/18 needle. Thread was stitched into 2 ply #8 Cotton Duck (18 oz fabric). Although the thread sewed without breaks, excessive shedding was noted for each speed around the presser foot after each pattern (Appendix D). This degree of shedding is not normal for a synthetic core thread. Appendices E and F show stitches magnified from the 2,000 spm pattern. Stitches appear clean; however, it would appear from the photographs that fiber distribution along the length of the thread is variable.

Phase 1 (May) thread was also successfully sewn at 1,400, 1,800 and 2,200 spm, although with similar results – excessive shedding. This extreme test would appear to be an indicator that PyroTex's tenacity of 2.81 g/den may be too low for an industrial sewing thread.

3.2 Phase 2

3.2.1 Yarn and Thread Production

This thread should have been processed under identical conditions to Phase 1; however, Charles Craft's technician did not set the spinning frame up to produce 'S' twist. Subsequently the thread twist ended up 'S' twist, opposite from Phase 1. The preferred finished twist direction for a sewing thread is 'Z'; however, with most apparel sewing threads an 'S' twist thread will, with most patterns, sew perfectly well in this direction; in fact, most twin needle sewing machines prefer 'S' twist in the left needle. The

decision was made, following sewing trials, to continue with this construction and not start Phase 2 from scratch.

3.2.2 Dyeing

Hickory Yarns could not dye this bi-component thread a solid shade of Tan 499.

All 12 lab trials, which comprised formulations and modifications of component or dual bath processes of disperse, basic and one reluctant trial of pre-metalized acid dye formulation, failed. The thread was finally processed as a lot purely to allow for a wet process at a temperature of about 266 °F to evaluate physical properties. With the correct knowledge and/or experience, it should be possible to dye this combination of raw materials.
Between Phase 1 and Phase 2, Hickory Yarns ran 24 dye trials in an attempt to dye a solid, level Tan 499.

3.2.3 Final Winding

The thread was lubricated straight from the dyed package without the use of an intermediate pre-lubrication process. Final put-up was a 7” plastic cone. Eighteen cones were produced and each cone contained 1,500 yd. Physical properties are listed in Table 3.

TABLE 3

Phase 2 Physical Properties

	Count (NeC)	Breaking Strength (lb)	Elongation @ Break (%)	Twist Singles 'Z'	Twist Plied 'S'	DHS (%)	Lube Content (%)
Anticipated Values	8.00	6.00	Max 35%	17.00	14.80	1.50	8.00
Phase 2 (May)	7.16	6.19	19.63	19.69	14.36	2.00	8.44

Note: The Dry Heat Shrinkage (DHS) test was done in accordance with ASTM D 4974 – Standard Test Method for Hot Air Shrinkage of Yarn and Cord Using a Thermal Shrinkage Oven using the following parameters: 177 ^{0}C / 2 min / 9 g. The other testing is conducted in accordance with ASTM D 204 – Standard Test Methods for Sewing Threads.

Anticipated physical properties were for dry, un-lubed thread, hence the lighter count.

Physical properties are acceptable and should allow for good sewing performance. Elongation at break is lower than for Phase 1 which is due to the core having been processed through an oven under tension and heat set at 380 ^{o}F.

3.2.4 Sewing Trials

The thread was successfully sewn utilizing an internally developed multidirectional pattern at 1,400, 1,800 and 2,200 stitches per minute using a Juki LK-1942GA sewing machine, equipped with a Schmetz 110/18 needle (Appendix F). Thread was stitched into 2 ply #8 Cotton Duck (18 oz fabric). Although the thread sewed without breaks, excessive shedding was noted for each speed around the presser foot and bobbin casing after each pattern. This degree of shedding is not normal for a synthetic core thread.

This extreme test and subsequent shedding would appear to be an indicator that PyroTex's tenacity of 2.81 g/den may be too low for an industrial sewing thread. With the core to sheath ratio at 50:50, shedding may also be more noticeable with a low tenacity fiber than if it were at 30%, which is a more standard sheath level for a synthetic core thread (70:30).

Shade changes in the stitch indicate considerable movement and disturbance of the sheath during processing, and extreme accumulations of lint around the presser foot and bobbin case during sewing are strong indicators that the polyester core may not be receiving the level of protection originally hoped for from this construction. Only FR/HR testing of the seam will determine the true level of protection.

As a no charge addition to Phase 1 and Phase 2, a 50:50 construction of treated 170 denier Polyester/Nomex fiber was manufactured to NeC 16/2 and sew tested. Physical properties are listed in Table 4.

TABLE 4

50:50 Polyester/Nomex Physical Properties

	Count (NeC)	Breaking Strength (lb)	Elongation @ Break (%)	Twist Singles 'Z'	Twist Plied 'S'	DHS (%)	Lube Content (%)
Anticipated Values	8.00	6.00	Max 35%	17.00	14.80	1.50	8.00
Phase 2 (May)	7.65	6.72	13.30	18.12	11.91	2.00	8.50

Note: The Dry Heat Shrinkage (DHS) test was done in accordance with ASTM D 4974 – Standard Test Method for Hot Air Shrinkage of Yarn and Cord Using a Thermal Shrinkage Oven using the following parameters: 177 ^{o}C / 2 min / 9 g. The other testing is conducted in accordance with ASTM D 204 – Standard Test Methods for Sewing Threads.

Thread was stitched into 2 ply #8 Cotton Duck (18 oz fabric) at 1,400, 1,800 and 2,200 spm with very little shedding (Appendix G and Appendix H).

This Polyester/Nomex construction shows excellent promise; therefore, a 70:30 ratio should be investigated since it would meet cost reduction requirements of effort - Nomex/Aramid components will not exceed 30% by weight.

4. Conclusions

The NeC 16/2 thread produced in Phase 1 and Phase 2 has the physical properties required to perform as a sewing thread; however, due to the excessive linting and fiber shedding during certain processing steps, and particularly the sewing operation, this particular modified acrylic fiber does not appear to have sufficient tenacity to be suitable as a sewing thread component; therefore, additional work to establish a suitable dyeing formula and procedure for this bi-component thread is no longer necessary.

5. Recommendations

A higher tenacity FR/HR fiber such as Nomex should be used as a sheath when covering a FR treated core such as polyester. This construction would still significantly lower manufacturing costs. A suitable dyeing procedure should be developed using a subcontractor with prior knowledge of both substrates.

This document reports research undertaken at the U.S. Army Natick Soldier Research, Development and Engineering Center, Natick, MA, and has been assigned No. NATICK/TR- 16/008 in a series of reports approved for publication.

6. References

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[2] US Patent No US 6,287,690 B1, Frank J. Land, Freeport, NY (US)

[3] http://www.tex.tuiasi.ro/biblioteca/carti/CARTI/Textile/Handbook%20of%20Technical%20Textiles/012.pdf

[4] ASTM D4974-04(2011), Standard Test Method for Hot Air Thermal Shrinkage of Yarn and Cord Using a Thermal Shrinkage Oven, ASTM International, West Conshohocken, PA, 2011, www.astm.org

[5] ASTM D204-02(2010)e1, Standard Test Methods for Sewing Threads, ASTM International, West Conshohocken, PA, 2010, www.astm.org

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Appendix A
16/2 Core Bundle No Treatment

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Appendix B
16/2 Core Single Thread

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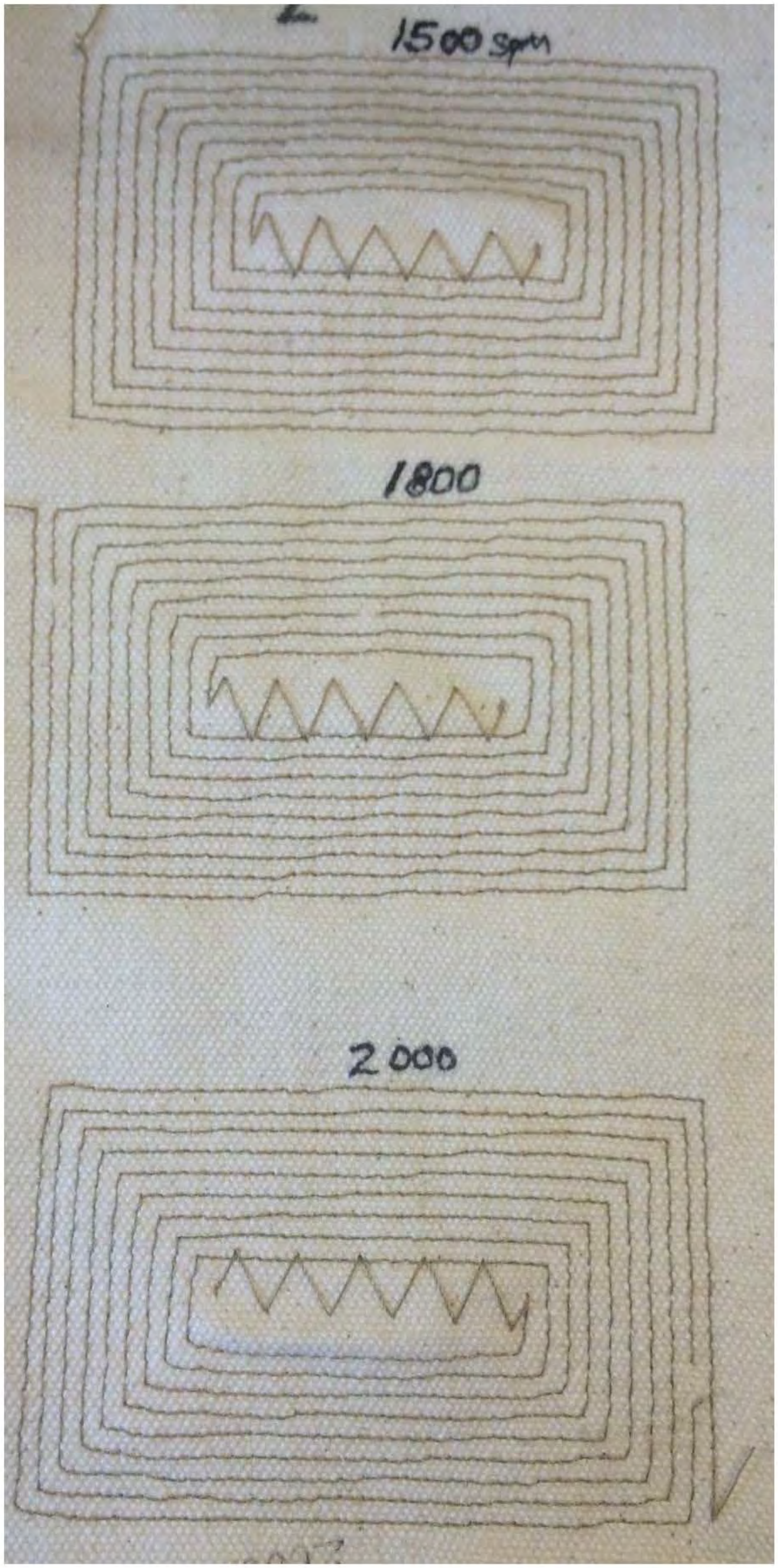
Appendix C
Phase 1 Stitch Pattern



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Appendix D
16/2 FR – Presser Foot

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Appendix E
16/2 Fabric Stitch

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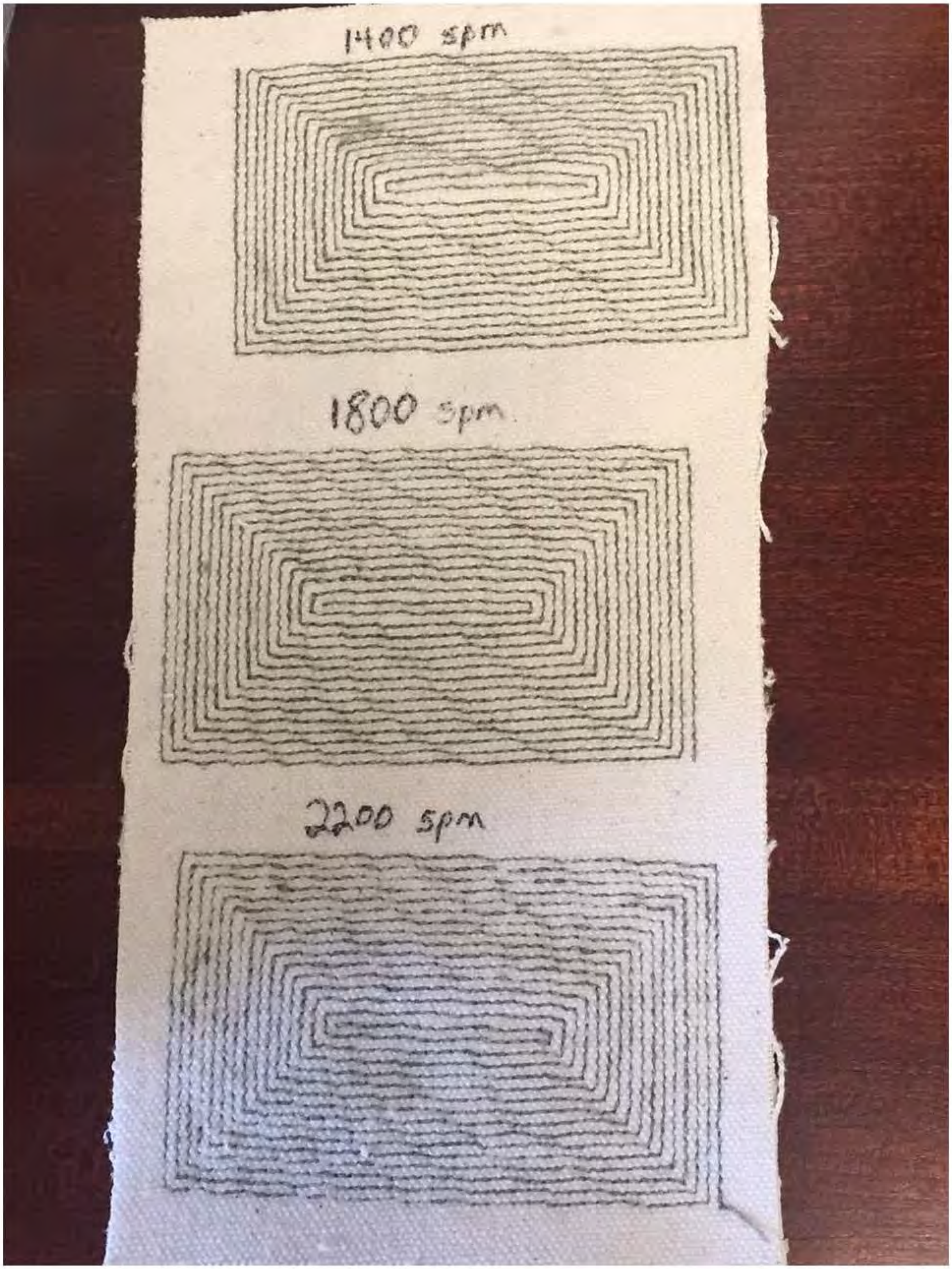
Appendix F
Phase 2 FR Polyester/Pyro-Tex®



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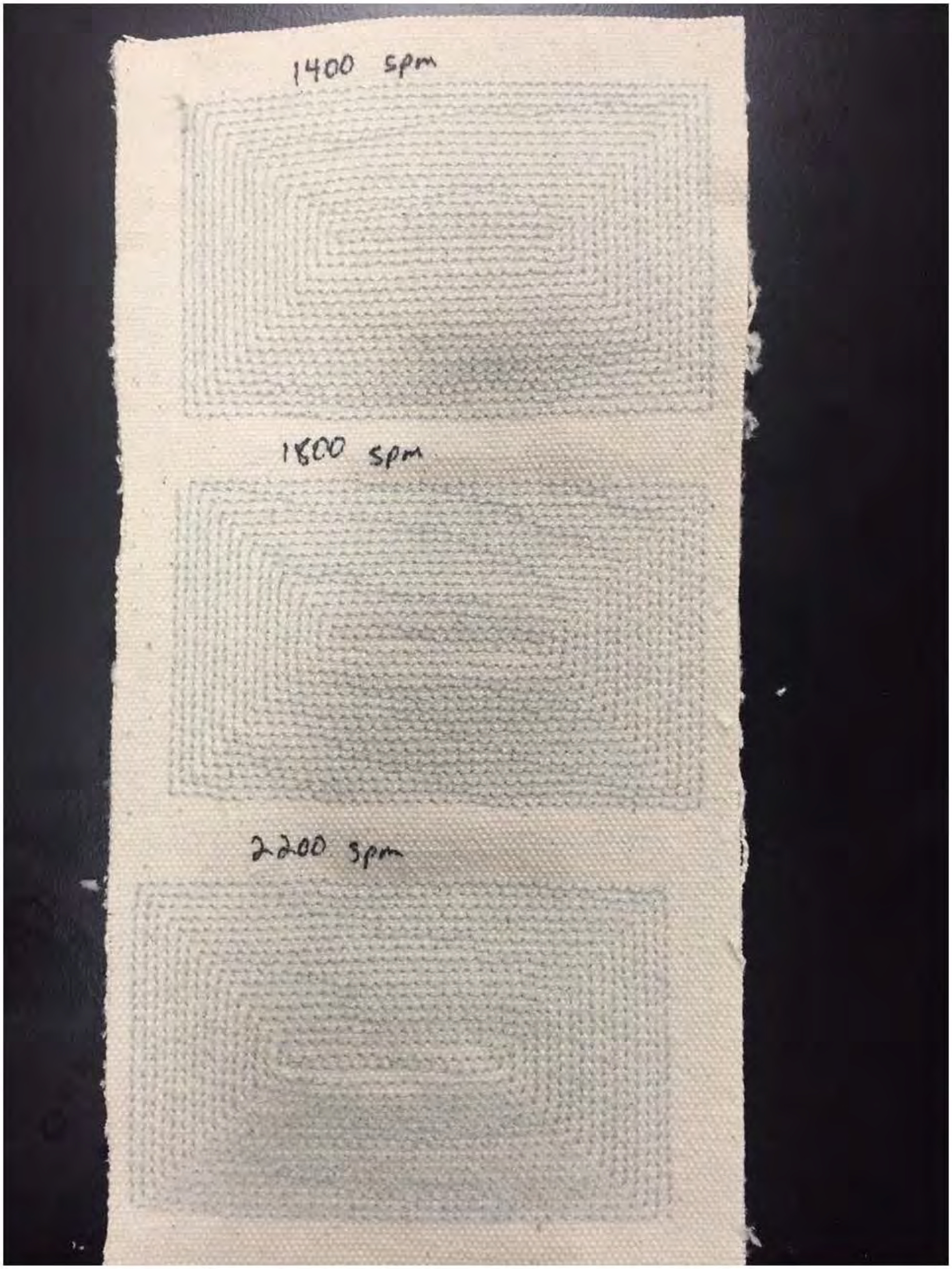
Appendix G
FR Poly/Nomex, 1400, 1800 and 2200 spm



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Appendix H
FR Poly/Nomex 2200 spm